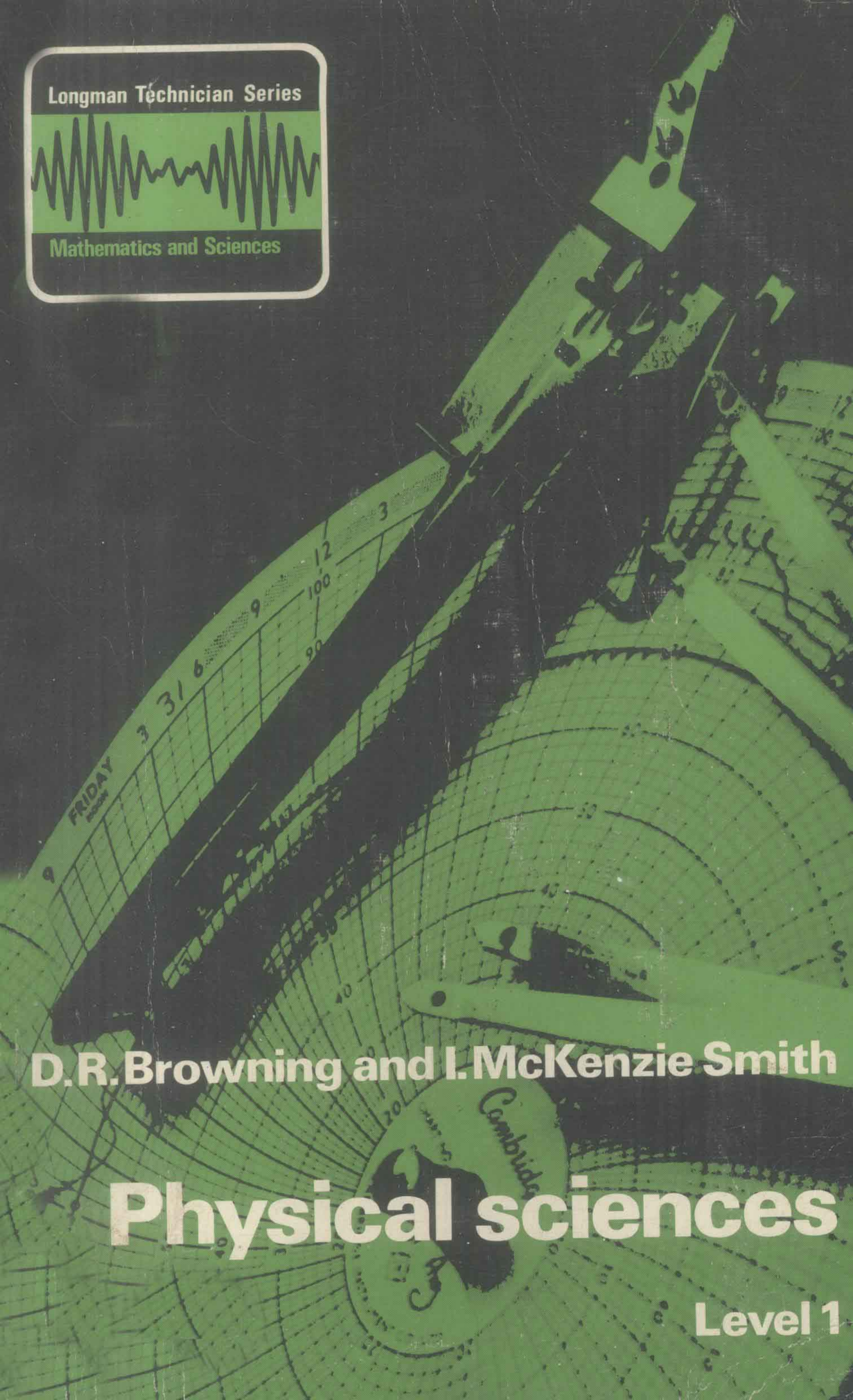

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Level 1

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Preface

We are blind and we would see,
We are bound and would be free,
We are dumb and we would talk,
We are lame and we would walk.

W. S. Gilbert

This book has been written specifically to meet the requirements of the Technician Education Council Level 1 unit in Physical Science (GEC U75/004), although in some cases the presentation has been broadened slightly to allow for college modified schemes. It will also be of value in many of the Physical Sciences courses being developed on a mode 3 basis at CSE and 'O' level.

SI Units and modern nomenclature and terminology are used throughout although in some cases the explanations (e.g. naming of chemical compounds) are much simplified.

The review questions and examples at the end of each chapter are designed to ensure that the student has attained the objectives of the unit and should be suitable as a basis for in phase assessment.

The authors wish to express their appreciation to colleagues for the criticising the manuscript, to the publishers for their continued help and co-operation and to their wives for their patience and lack of criticism during the preparation of the book.

List of symbols and abbreviations

	Symbol	Unit Abbreviation
Acceleration, linear	a	m/s^2
Area	A	m^2
Charge	Q	C
Current	I	A
Density	ρ (rho)	kg/m^3
Efficiency	η (eta)	—
Electric potential	V	V
Electromotive force	E	V
Energy	W	J
Force	F	N
Length	l	m
Mass	m	kg
Power, active	P	W
Pressure	p	Pa
Resistance	R	Ω
Resistivity	ρ (rho)	Ω m
Temperature coefficient	α (alpha)	/°C
Temperature difference	θ (theta)	°C
Time	t	s
Work	W	J
Velocity, linear	u	m/s
Volume	V	m^3

Contents

Chapter 1

Units of measurement

It is fascinating to look at the universe and our world within it and to realise that no matter how complicated the universe appears to be there is an order and design behind it all. The role of the scientist is to investigate this order by observation of, and experimentation with, the structures upon which our universe is built and, with the engineer, to use the knowledge gained for the benefit of mankind.

In order to do this he must measure the properties he studies in a meaningful and accurate way. This is necessary to be able to critically assess the results of his experiments.

Our first attempts at measurement were related to the world about us. For example, length was measured by relating it to certain body distances, e.g. the length of a foot. Because of the wide variation in size between people this kind of measurement was very rough. Nowadays we are moving towards the use of an international system of units which will provide us with an international language of measurement we can all understand and use. The system being adopted is known as the *Système International d'Unités* (SI). It will be used exclusively throughout this book.

It was introduced in 1960 and has now been adopted by the majority of countries as the official, and only legal, system of measurement. One of its main advantages is that it is coherent. A system is said to be coherent if the product or quotient of any two quantities, as measured in the system, gives the resultant quantity in the corresponding unit of the system. For example:

unit length × unit breadth = unit area (page 4).

unit mass × unit acceleration = unit force (page 44)

The units are arbitrarily chosen and a certain quantity is assigned a value of unity on the basis of a conveniently chosen standard. These units are known as basic units. This will be clearly shown in the remainder of this chapter.

If we look carefully at the various things we can measure we see that they can all be expressed in terms of:

length
mass
time
amount of material
temperature
electric current
luminous intensity

We will now consider the first three of these, and their related units, in turn. The remainder will be discussed at appropriate places in the text.

1. Length, area and volume

A *length* may be expressed as the interval or distance between two points. The standard unit of length is the *metre.* Until 1961 this was defined as the distance between two finely drawn lines on a metal bar which is kept in the International Bureau of Weights and Measures just outside Paris. Such a standard is not readily accessible on a world-wide basis. Nowadays the metre is defined in terms of the wavelength of the orange light emitted by krypton gas. This can be accurately measured in any part of the world to a precision of one in a hundred million.

All the other units of length measured in this system of units vary from the metre by factors which are positive or negative powers of 10

1 000 000 000 000 metres (10^{12} m)	=	1 terametre	(1 Tm)
1 000 000 000 metres (10^{9} m)	=	1 gigametre	(1 Gm)
1 000 000 metres (10^{6} m)	=	1 megametre	(1 Mm)
1 000 metres (10^{3} m)	=	1 kilometre	(1 km)*
0.001 metres (10^{-3} m)	=	1 millimetre	(1 mm)
0.000 001 metres (10^{-6} m)	=	1 micrometre	(1 μm)
0.000 000 001 metres (10^{-9} m)	=	1 nanometre	(1 nm)
0.000 000 000 001 metres (10^{-12} m)	=	1 picometre	(1 pm)

Other SI units are treated in the same way. One other factor which is used for the metre only is the centimetre (10^{-2} m).

The simplest instrument for measuring length is the metre rule which is

* k may be replaced in the future by K so that all positive powers of 10 will be represented by capital letter prefixes.

1 metre long and is divided into millimetres. In some cases a rule is difficult to use or is not accurate enough and other instruments have to be used (Fig. 1).

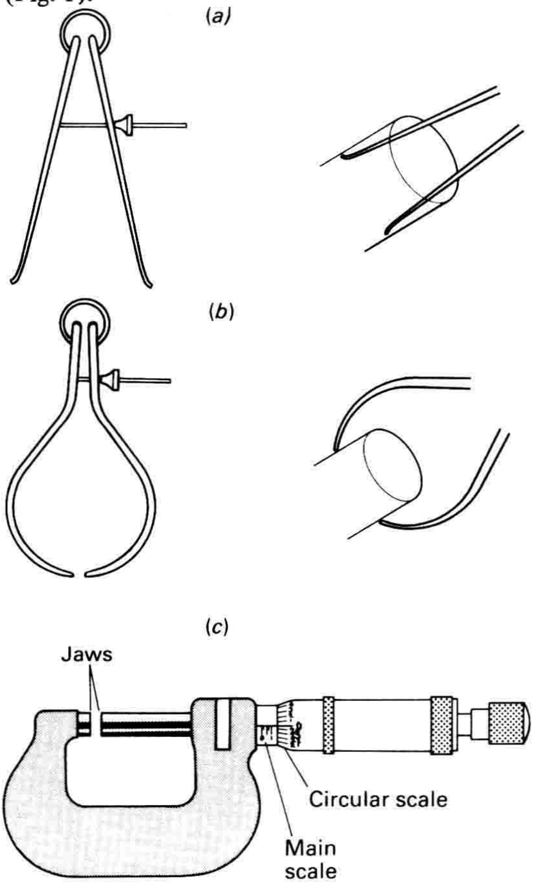

Fig. 1 Instruments for measuring length

(*a*) Internal calipers are designed to measure internal 'lengths' such as the internal diameter of tubing.

(*b*) External calipers are designed to measure external diameters of, for example, tubing and rod.

(*c*) Micrometer screw gauges are designed to measure the thickness of slim objects. They have two scales.
The main scale has divisions of 0.5 mm.
The circular scale moves forward 0.5 mm for one complete revolution. Since this has 50 divisions on it one division is 0.01 mm.
The object to be measured is placed between the jaws and these are closed until they just meet the object and the measurement, accurate to 0.01 mm, read from the scales.

Length	Symbol: l	Unit: metre (m)

Area is a measurement of the extent of a surface and is measured by multiplying a length by a length. For example the area of this page is found from:

the length from top to bottom of the page × the length from side to side of the page

Some common areas are:

Area of a square = length of side × length of side
Area of a circle = constant (π) × length of radius × length of radius
Area of a triangle = $\frac{1}{2}$ × length of base × length of height

If length is measured in metres then area is measured in:

metres × metres or metres^2

Also $1\ m^2 = 1\ m \times 1\ m = 100\ cm \times 100\ cm = 10\,000\ cm^2 = 10^4\ cm^2$

Area	Symbol: A	Unit: square metre (m^2)

Volume is the space occupied by a body and is measured by multiplying a length by a length by a length. For example, the volume of this book is found from:

the length from top to bottom of a page × the length from side to side of the page × the length from back to front of the book

Some common volumes are:

Volume of a cube = length of side × length of side × length of side
Volume of a sphere = constant ($\frac{4}{3}\pi$) × length of radius × length of radius × length of radius
Volume of a cone = constant ($\frac{1}{3}\pi$) × length of cone × length of radius of base × length of radius of base

If length is measured in metres then volume is measured in:

metres × metres × metres or metres^3

Also $1\ m^3 = 1\ m \times 1\ m \times 1\ m = 100\ cm \times 100\ cm \times 100\ cm = 1\,000\,000\ cm^3 = 10^6\ cm^3$

Hence length $= 1\ m = 100\ cm = 10^2\ cm$
area $= 1\ m^2 = (100\ cm)^2 = 10^4\ cm^2$
volume $= 1\ m^3 = (100\ cm)^3 = 10^6\ cm^3$

One volume unit which is very common is the litre. It is defined as $1\,000\ cm^3$.

i.e. $1\ \text{litre} = 1\,000\ cm^3$

$$= \frac{1\,000}{100 \times 100 \times 100}\ m^3 = 0.001\ m^3 = 1 \times 10^{-3}\ m^3$$

Also in the context of the litre another unit is often used, the decimetre (dm), which is one-tenth of one metre (1×10^{-1} m).

$\therefore$ $1\ \text{litre} = 1 \times 10^{-3}\ m^3 = 1\ dm^3$

The volume of an irregular solid may be found by the following method.

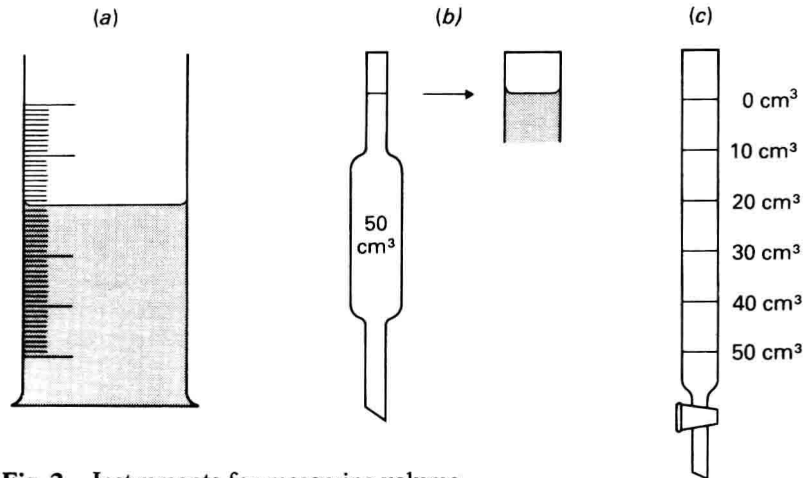

Fig. 2 Instruments for measuring volume

(*a*) A measuring cylinder can have many volumes from a few cm^3 to several dm^3. This one is 50 cm^3, each long line representing 10 cm^3 and each short one 1 cm^3, these values are always marked on the cylinder; the volume in the cylinder at present is 30 cm^3.

(*b*) A bulb pipette has the volume marked on the bulb when the liquid reaches the mark, as shown. As with measuring cylinders many sizes are available. A suction filler is used to suck the liquid into the pipette.

(*c*) A burette is used to measure out accurate volumes. The most common burette has a volume of 50 cm^3, divided into 10 cm^3, then 1 cm^3, then 0.1 cm^3 units. The volume required is as follows:
The burette reading is, say, 8.2 cm^3. 24.2 cm^3 are required. The liquid in the burette is run out carefully, using the tap, until the reading is 8.2 + 24.2 = 32.4 cm^3.

Half fill a measuring cylinder (Fig. 2) with water. Note the volume. Place the solid in the water and note the new volume.

The volume of water displaced by the solid = the volume of the solid
= the second reading – the first reading

A given volume of liquid is measured by using a measuring cylinder or a burette depending on the accuracy required. A pipette may be used when definite volumes are accurately needed (Fig. 2).

Volume | Symbol: V | Unit: cubic metre (m^3).

Example 1. *Determine the volume of a cube of length 12 mm in metre³.*

$$\text{Volume} = \frac{12}{1\,000} \times \frac{12}{1\,000} \times \frac{12}{1\,000} = \frac{1\,728}{10^9}$$

$$= \frac{1.728 \times 10^3}{10^9}$$

$$= \underline{1.728 \times 10^{-6}\ m^3}$$

Example 2. *Find the area of a triangle of height 6.5 cm and of base length 3.1 cm.*

$$\text{Area} = (6.5 \times 3.1)/2 = 10.1\ cm^2$$
$$= \underline{0.101\ m^2}$$

Example 3. *A measuring cylinder contains 50 cm³ of water. When solid X is added the volume increases to 73.4 cm³. What is the volume of the solid?*

$$\text{Volume} = 73.4 - 50 = 23.4\ cm^3$$
$$= 23.4 \times 10^{-6}\ m^3$$
$$= \underline{2.34 \times 10^{-5}\ m^3}$$

2. Mass

Mass is different from other quantities in that it is a fundamental property of matter. It is defined as the amount of matter in any chosen object. For example if we take a given sample of iron it will have a definite mass. No matter what we do to this sample, heat it, cool it, melt it, we will not alter its mass although we may alter its shape and volume. The mass of a substance is compared to that of a standard cylinder of iridium–platinum which is kept in the International Bureau of Weights and Measures. This is defined as having a mass of 1 kilogramme (kg). It is not possible to compare the substance against the standard but we can buy sets of brass standard masses. The determination of the mass of an object is carried out by placing the object on the left-hand pan of a balance (Fig. 3) and adding the brass standards to the right-hand pan

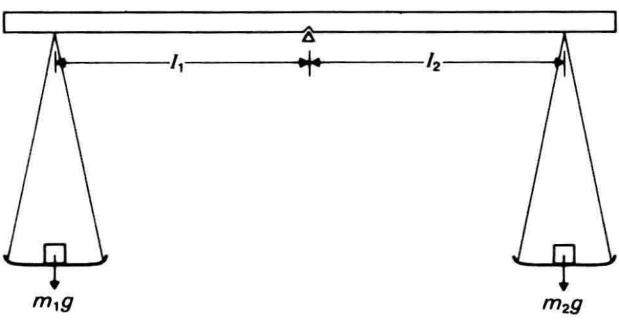

Fig. 3

until both arms balance. The mass of the object is now equal to that of the sum of the standards (page 6).

Mass | Symbol: m | Unit: kilogramme (kg)

The kilogramme is a large mass and we often use the smaller mass of 1 gramme (g) for measurement purposes.

$$1 \text{ gramme} = \frac{1}{1\,000} \text{ kilogramme} = 10^{-3} \text{ kilogramme} \qquad 1 \text{ g} = 10^{-3} \text{ kg}$$

also $1 \text{ kg} = 10^3 \text{ g}$

Very large masses are often measured in tonnes, where

1 tonne = 1 000 kg

3. Density and relative density

Since mass is a measure of the nature and quantity of a substance and volume is a measure of its quantity only, it is reasonable to assume that if we divide mass by volume we should get a property which is dependent only on the nature of the substance. This property is known as the density and since the standard units of mass and volume are the kilogramme and metre^3 respectively the corresponding unit for density is obtained as follows

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{\text{kg}}{\text{m}^3} \quad \text{or} \quad \text{kg m}^{-3}$$

The density of a pure substance has a given value and any deviation from this value denotes impurity. Therefore density can be used both as a method of characterisation of a substance and as a means of detecting impurity.

Density | Symbol: ρ | Unit: kilogramme per metre^3 (kg/m^3)

It may be determined from the values of corresponding masses and volumes. In the case of liquids a density bottle may be used (Fig. 4).

Thoroughly clean and dry the density bottle (to make sure it contains no impurities) and determine its mass with its stopper (x_1 grammes). Fill the bottle with water so that when you replace the stopper the water flows out of the hole at the top. Carefully dry the top of the stopper with blotting paper

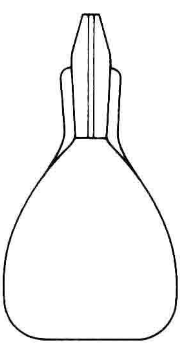

Fig. 4 Density bottle

making sure you do not remove any water from the hole. Determine the mass of the water and the density bottle (x_2 grammes).

$\therefore$ Mass of the water = $(x_2 - x_1)$ grammes

but 1 g of water has a volume of 1 cm^3 (note and remember this fact)

$\therefore$ Volume of the water = $(x_2 - x_1)$ centimetre^3
$\therefore$ Volume of the density bottle = $(x_2 - x_1)$ centimetre^3

Repeat the experiment with the liquid under investigation. If the mass of the bottle and the liquid is x_3 grammes, then

the mass of the liquid = $(x_3 - x_1)$ grammes

and

$$\text{the density of the liquid} = \frac{x_3 - x_1}{x_2 - x_1} \text{ grammes per centimetre}^3$$

$$= \frac{x_3 - x_1}{x_2 - x_1} \times 10^3 \text{ kilogrammes per metre}^3$$

It is sometimes useful to determine the relative density of a substance, where

$$\text{relative density} = \frac{\textit{density of the substance}}{\text{density of water}} \quad \text{(measured in the same units)}$$

Water is a useful standard since its density is 1 g/cm^3 or 10^3 kg/m^3. Hence the relative density in the above case is $\dfrac{(x_3 - x_1)}{(x_2 - x_1)}$ no matter what the units of density are. This is as expected since relative density is formed by one density being divided by another and is therefore only a number. Hence it will always have the same value, irrespective of units, which can prove useful.

Example 3. *51.5 cm^3 of sodium has a mass of 50 g. Determine its density.*

$$\text{Density} = \frac{50}{51.5} \text{ g/cm}^3$$

$$= 0.97 \text{ g/cm}^3 = 0.97 \times 10^3 \text{ kg/m}^3$$
$$= \underline{970 \text{ kg/m}^3}$$

Example 4. *The density of ethanol is 800 kg/m^3. What is the mass of 250 cm^3?*

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Mass = density × volume
= $800 \times 250 \times 10^{-6}$ kg = 0.2 kg or $\underline{200 \text{ g}}$

Example 5. *The density of iron is 7 800 kg/m^3. What is the volume of 0.6 kg?*